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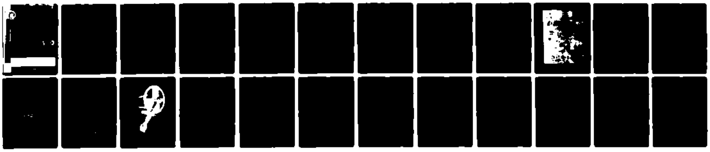

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TECHNICAL REPORT: NAVTRAEQUIPCEN IH-337

A VISUAL TECHNOLOGY RESEARCH SIMULATOR FOR VERTICAL TAKE OFF AND LANDING (VTOL)

Jack W. Herndon
Naval Training Equipment Center

March 1982

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A VISUAL TECHNOLOGY RESEARCH SIMULATOR FOR VERTICAL TAKE OFF AND LANDING (VTOL)

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This report provides an overall description of Visual Technology Research Simulator (VTRS) Vertical Take Off and Landing (VTOL) visual system installed at the Naval Training Equipment Center in Orlando, Florida. The report includes descriptions of the system hardware and capabilities.

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SECTION I

INTRODUCTION

In 1973 the Navy issued a Technical Development Plan which stated the urgent need to provide advances in the technological and pedagogical tools required for dramatic expansion of the use of simulator/training devices in all phases of naval weapon system training. This plan further stated that the need resulted from:

a. Decreased availability of advanced systems for training

b. High procurement/operational cost of weapon systems now used as trainers

c. High development/maintenance cost with large inventory of dedicated trainer aircraft

d. High training related accident rate

e. Reduced opportunity for training in the operational environment.

Soon after this plan was issued, the oil crisis emerged adding a very critical need to develop and support effective energy saving policies. In response to these needs the Navy established the Aviation Wide Angle Visual System (AWAVS) as a research tool to support cost/training-effective technology for flight trainers. The initial thrust of this program was directed to accomplish objectives relating to flight training simulators, with principal emphasis on visual systems. Upon acquiring a basic capability it became obvious that the program was not limited to flight simulator applications but could be effective in meeting research objectives for other simulators requiring wide angle visual systems, including surface navy tasks such as shiphandling and underway replenishment at sea. During 1980, AWAVS was changed to Visual Technology Research Simulator (VTRS) to reflect the broader mission.

The primary objectives of the VTRS program are: (1) to provide improved wide angle visual system technology for flight simulators and to evaluate this technology in terms of system performance; (2) to determine simulator effectiveness as a function of the fidelity of visual parameters as they interact with other systems, tasks, and behavioral variables; and (3) to provide hardware design criteria for future simulator procurements. Above all, the purpose of the VTRS program is to support today's training systems acquisition with demonstratable technology and expertise. To meet these objectives the hardware/software capability developed emphasizes system variability to permit investigations of the effects of visual system parameters on pilot performance in specific task environments. The initial equipment configuration of VTRS for Conventional Take Off and Landing (CTOL) system tasks is described in a paper by Chambers (1977). This report will describe the Vertical Take Off and Landing (VTOL) system characteristics.

Two major categories of research will be conducted to meet the objectives of VTOL VTRS. The first category, termed Hardware Performance Research, concerns engineering evaluation of the system in terms of its physical characteristics, while the second area, Human Performance Research, involves human factors evaluations of the system in terms of pilot performance and training effectiveness. The initial engineering evaluation is directed toward validation of the system to simulate the flight performance of the SH60B Seahawk. The initial visual scene is of the FFG-7 of the LAMPS MK III system and is provided by a CIG data base. Data bases for future follow-on tasks will be validated for such tasks as low level flight, confined area maneuvering and formation flight. The engineering evaluation is concerned also with performance of critical subsystems; such as the cockpit instrumentation, the control loading system and the color light valves. Component and subsystem reliability and maintainability data is a primary concern and will be collected over the life of the program.

The emphasis of the Human Performance Research is on studying the design of simulators that will be used chiefly for the teaching of advanced flying skills, and for the maintenance of pilots' proficiency in these skills. The tasks to be studied may be classified as involving either air, sea or ground operations. In many cases, the importance of a particular research topic may change according to the piloting task being studied. This is especially true in the case of visual system parameters. For example, a wide field of view may not be required for some landing approaches. In addition, visual parameters vary in importance due to cost considerations. If a certain visual system capability can be provided cheaply at a high level of realism, it is less important to study the effects of reduced fidelity in that parameter than in one for which high fidelity comes only at a very great cost. Priorities, therefore, must be established on the basis of such factors as cost, complexity, and relevance to a particular task. Tasks that will be addressed include day destroyer operations, night destroyer operation, autorotation, field take offs and landings, confined area maneuvering, low-level flight, air-to-ground weaponry and formation flying. Topics which will be considered for investigation for each of these tasks are: image quality, image fidelity, image generation techniques, image presentation techniques, brightness, contrast color, scene content, field of view, viewing distance, visual-motion correspondence, G-seat motion parameters, simulated aircraft fidelity, pilot parameters, task difficulty parameters, training techniques and performance measurement techniques. The following section presents an overview of the VTRS VTOL that will provide the necessary research environment in which to conduct the hardware and human performance research. In addition to providing a research environment, the success of the program will depend on the research strategy. The research strategy is obviously important because it guides what information will be collected, how the studies are to be accomplished and the resultant quality of the information. A discussion of the research strategy methodologies is beyond the scope of this paper.

SECTION II

VTOL SIMULATOR

The VTOL Simulator development and installation complete the major VTRS facility acquisitions. Figure 1, is a block diagram showing the VTOL system. The major subsystems are:

a. Image Generation - Utilizes the VTRS Computer Image Generation (CIG) system. The system, originally a 2000 edge system, has been upgraded to 6000 edges. (GE Compu-Scene with PDP 11T55 computer.)

b. Computer System - Utilizes the VTRS computer system which consists of three Central Processing Units (CPUs): one for flight simulation; one for visual simulation and the third for executive control (SEL 32/75s). Figure 2 illustrates the VTRS Computer System. The fourth CPU shown is currently utilized as a stand-alone system for development work. The Computer System update rate is 30 Hz. A concise description of the hardware/software system is contained in technical note NAVTRAEQUIPCEN IH-329 (Hawkins, December 1980).

c. Visual System - Consists of two, full-color TV Light Valve (GE Model # PJ5150) projectors; special lens; and a 34 foot diameter Spitz display dome.

d. Cockpit Simulator - A replica of the LAMPS MK III, SH60B Seahawk helicopter cockpit which simulates controls and instruments as well as the appearance and feel of the operational aircraft (Figure 3). Cyclic, collective and directional pedal control loading is provided by a special McFadden variable force control loading system. Table 1 gives the Control Loader system specifications.

e. Experimenter/Operator (E/O) Station - Utilizes the VTRS E/O station. Software provides the helicopter flight instruments graphic display. Figure 4 shows the cockpit instrument CRT display which the E/O station operator uses to monitor pilot activity.

f. Interface - Utilizes the VTRS master controller in conjunction with subcontrollers in the VTOL support cabinets.

g. Motion System - An experimental G-Seat, installed in the VTOL pilot's seat, will be used for development and evaluation (Goodyear and NTEC). The characteristics of this system will be covered in a future report.

h. Sound Cueing - Aircraft and environmental sounds of the SH60B will be provided.

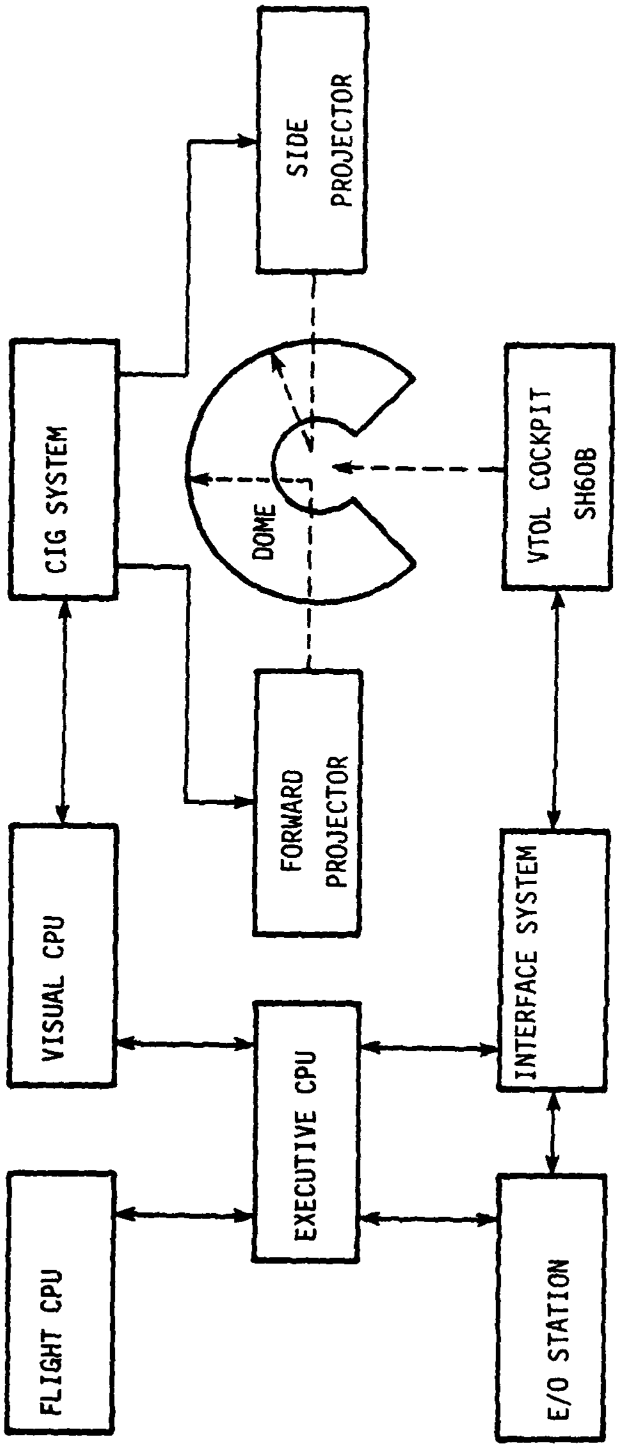

Figure 1. VTOL System Block Diagram.

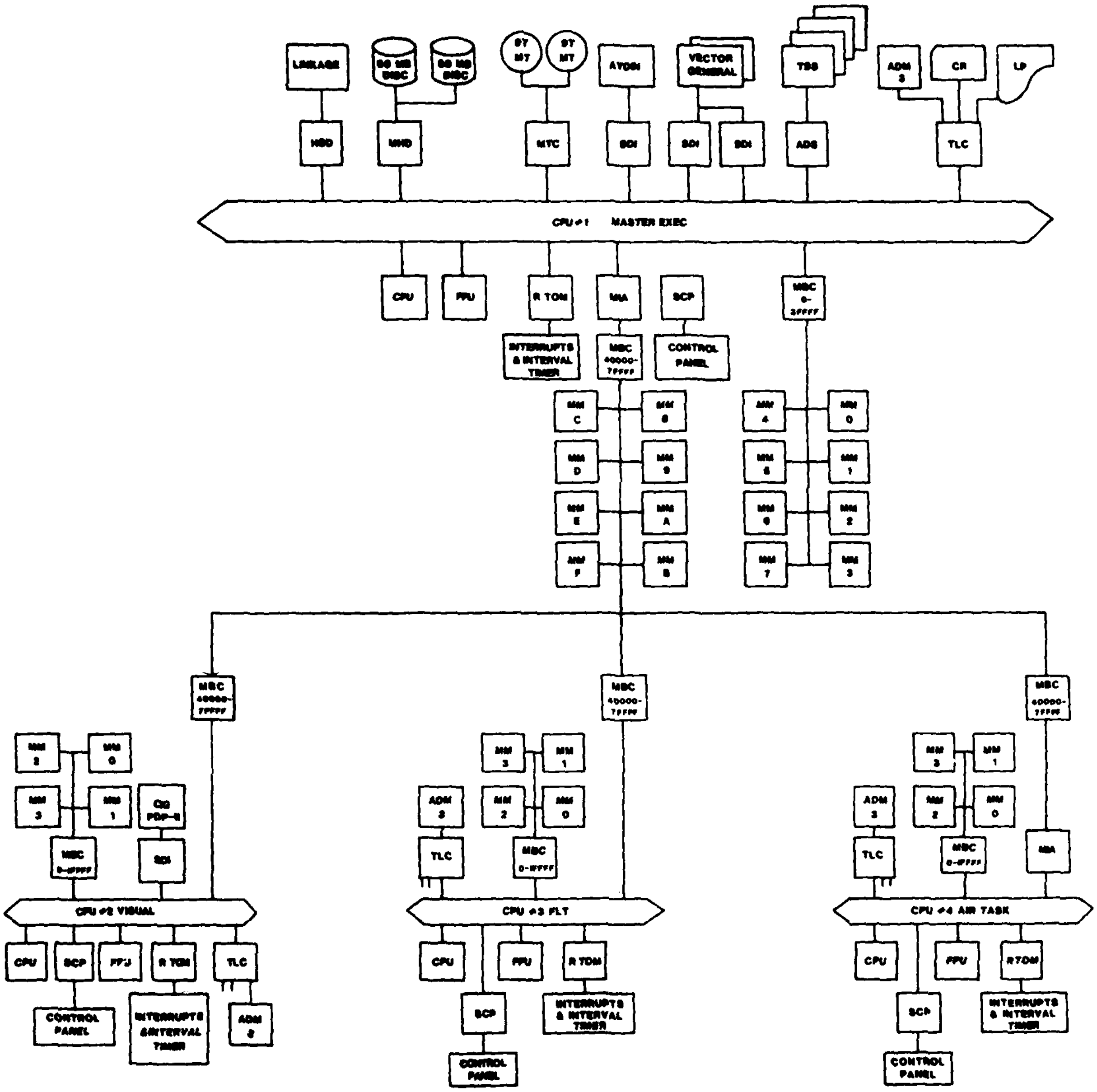

Figure 2. VTRS SEL Computer System.

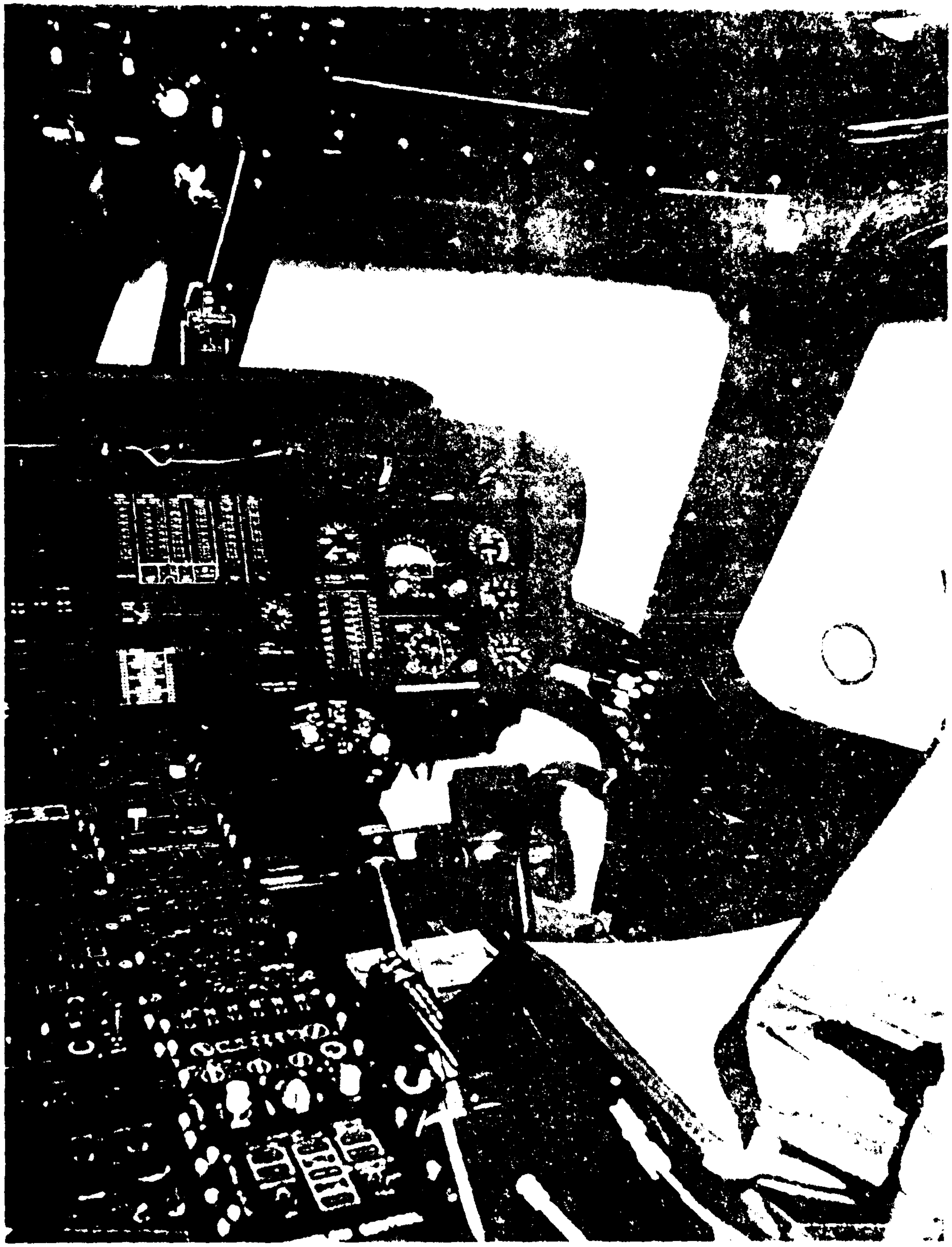

TABLE 1. SUMMARY OF CONTROL LOADER SPECIFICATIONS

PARAMETER	PITCH	ROLL	YAW	COLLECTIVE
Maximum Force Output (lb)	150	100	200	50
Maximum Travel (in)	±7	±7	±3.25	±7
Maximum Velocity (in/sec)	50	50	50	50
Force Threshold (lb)	0.20	0.20	0.20	0.20
Frequency Response (min) (force loop, -90 deg. phase point) (Hz)	50	50	50	50
Natural Frequency Range (min) (Hz)	0-5	0-5	0-5	0-5
Travel Limits (stops) (max)	0.1-1.0	0.1-1.0	0.1-1.0	0.1-1.0
Preload (breakout) Range (min) (lb)	0-25	0-25	0-25	0-10
Force Gradient Range (lb/in)	0-75	0-75	0-75	0-10
Force vs. Position Slope (max additive (lb/in)	200	200	200	200
Deadband Range (in)	0-2	0-2	0-2	0-2
Coulomb Friction Range (lb)	0-15	0-15	0-15	0-15
Damping (lb/in/sec)	0-0.5	0-0.5	0-3.0	0-0.5
Force vs. Velocity Slope (max additive (lb/in/sec)	3.0	3.0	3.0	3.0

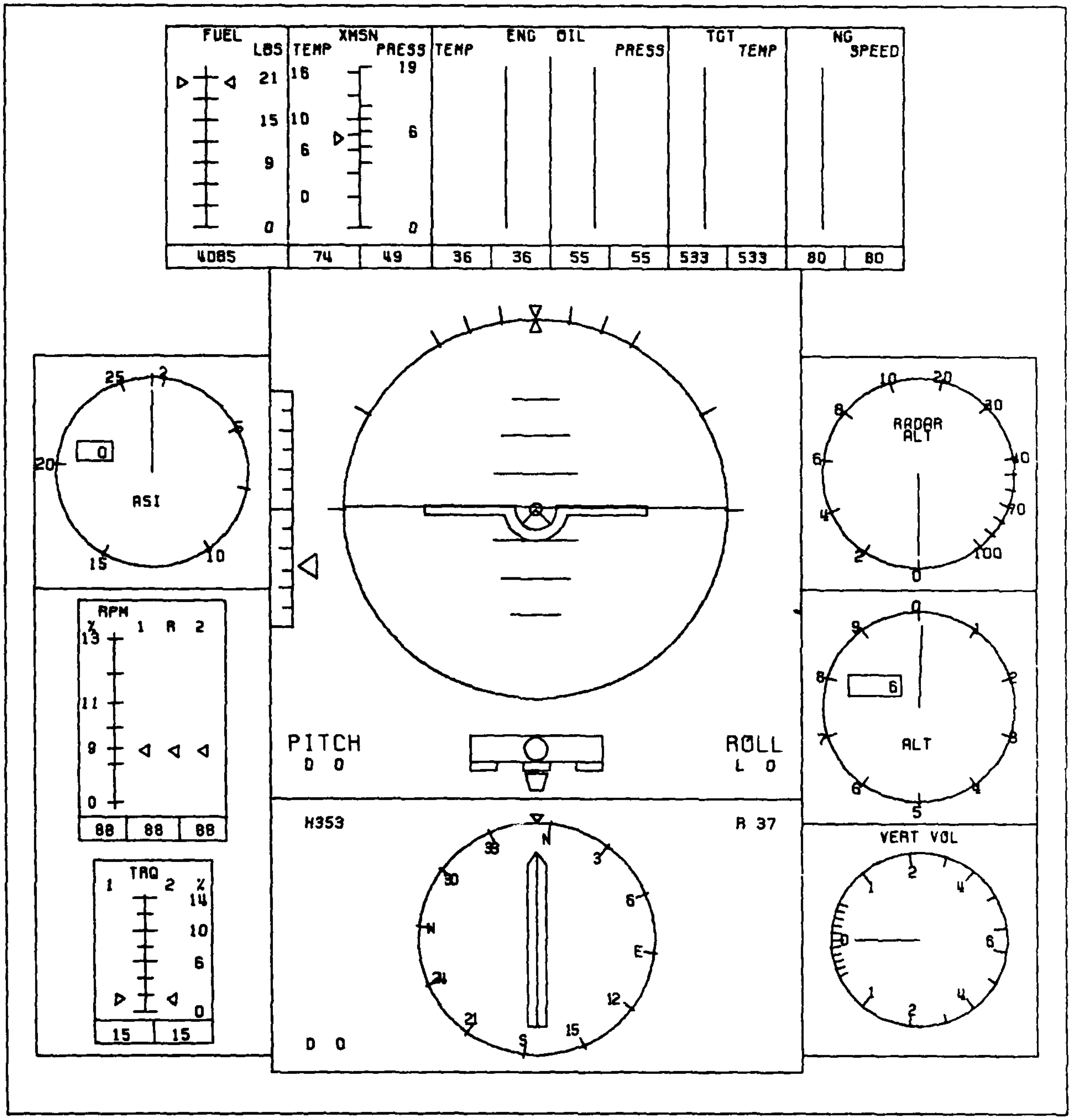

Figure 4. E/O Station CRT Instrument Panel Display.

SECTION III

VTOL VISUAL SYSTEM

The present system provides for two video channels, each covering 80° horizontal by 70° vertical field-of-view (FOV). Figures 5 and 6 show the geometric arrangement of the display system. The two projectors are mounted on a platform above the cockpit in a manner that allows the extended lens to be positioned as near to the center of the spherical screen as possible. The cockpit is mounted on a structure so that the design eye point for the pilot is also as near to the center of the screen as possible. The design eye point in this arrangement is located on the vertical axis of the screen eight inches above the screen center and 13.6 inches forward of the vertical axis. This arrangement minimizes the distortion correction required. Further, by minimizing the angle between the projection path and viewing path at the screen, more brightness can also be obtained when the screen surface has gain. Initially the screen surface will be a flat white which does not provide an increase in gain (gain = 1). Plans are to obtain a beaded screen material with a gain of approximately eight for application inside the dome and to evaluate the system performance with the resulting increase in brightness.

The emphasis of the visual system work at VTRS is with real image dome displays. The dome utilized for the VTOL projection screen is 34 feet in diameter, supported by an external ribbing and surfaced with preformed aluminum panels. The dome is attached to the building floor and accessed through a light-tight doorway. The door side of the dome is opposite the center of the viewing area and an entrance, 14 feet wide by 18.5 feet high, is provided to facilitate movement of cockpit and support structures. Two large doors, one above the other, are counterweighted and can be raised to provide the opening. A small personnel entrance door is provided in the lower large door.

PROJECTION SYSTEM

The 160°H x 70°V field-of-view (FOV) scene is projected by two GE PJ5150 color light valve TV projectors, each covering an 80° sector of the horizontal FOV. Edge matching between the two sectors is accomplished by positioning the view windows in the CIG system. The 70° vertical FOV extends 50° below the horizon and 20° above, to meet visual requirements for helicopters. To minimize the off-axis distance for the exit pupil of the projection lens, a special lens was developed to mate with the projector's standard T-6, series E, projection lens. The special lens extends the optical path by 32 inches between the projector output axis and the exit pupil axis. This allows the exit pupil to be positioned near the center of the spherical screen, as shown in Figure 5. The configuration of this special lens is shown in Figure 7. Figure 8 is a photograph of the lens mated to the projectors. The lens provides 114° diagonal FOV. It is radially symmetric f-θ for 80°H x 70°V FOV; rotatable 360°, (1) about the original optical axis of the light valve and

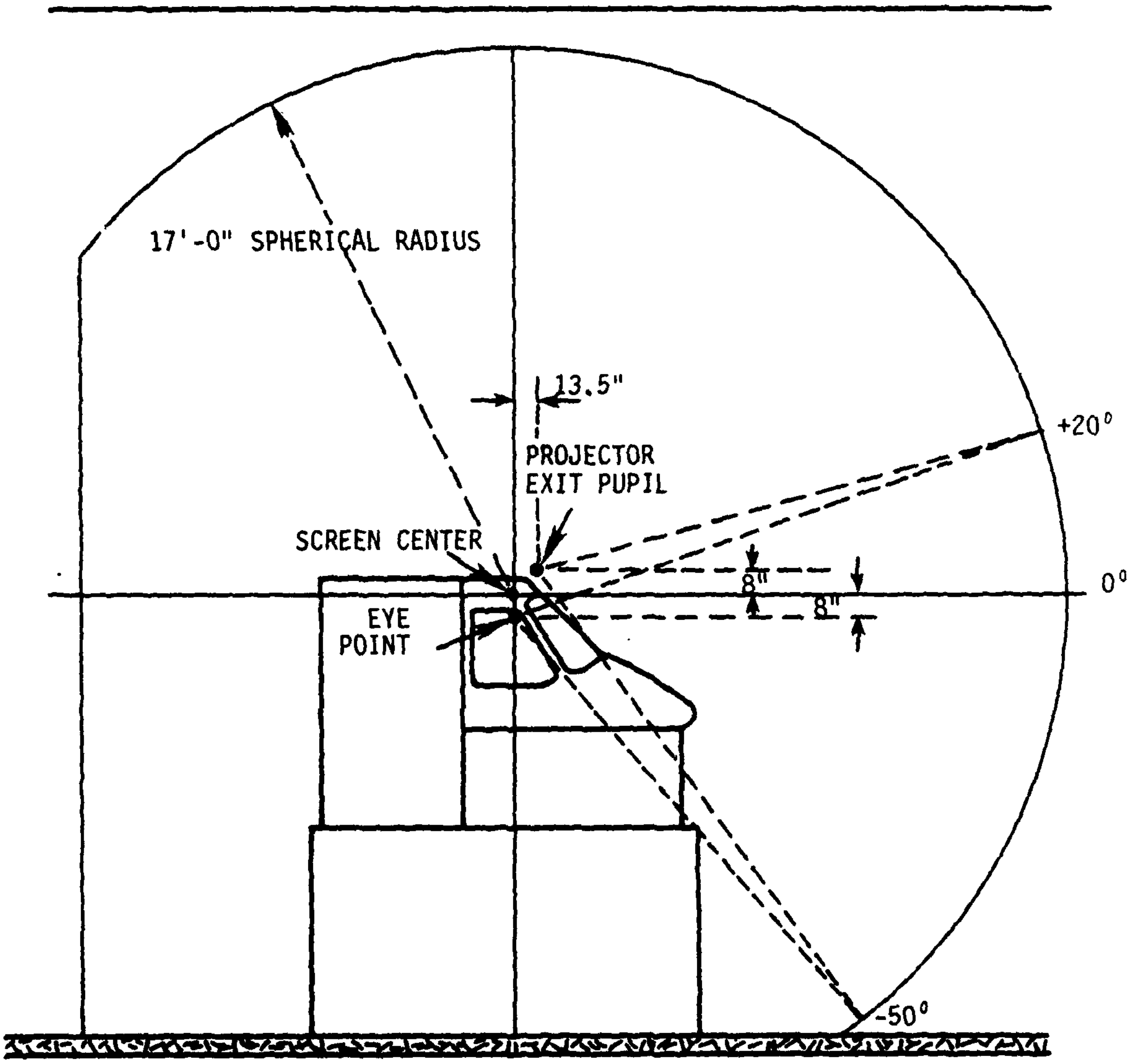

Figure 5. Display System Geometry (Side View).

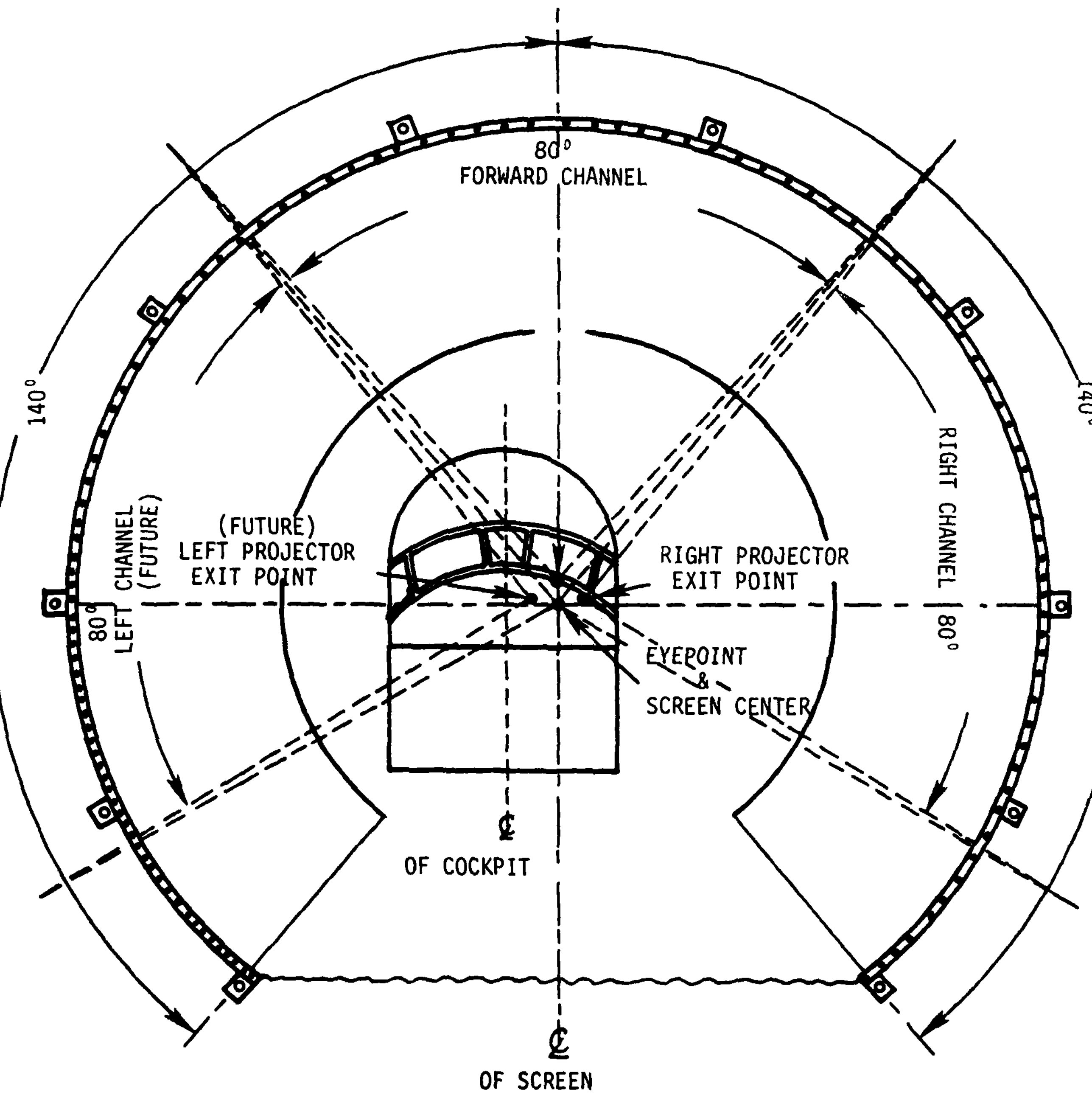

Figure 6. Display System Geometry (Plan View).

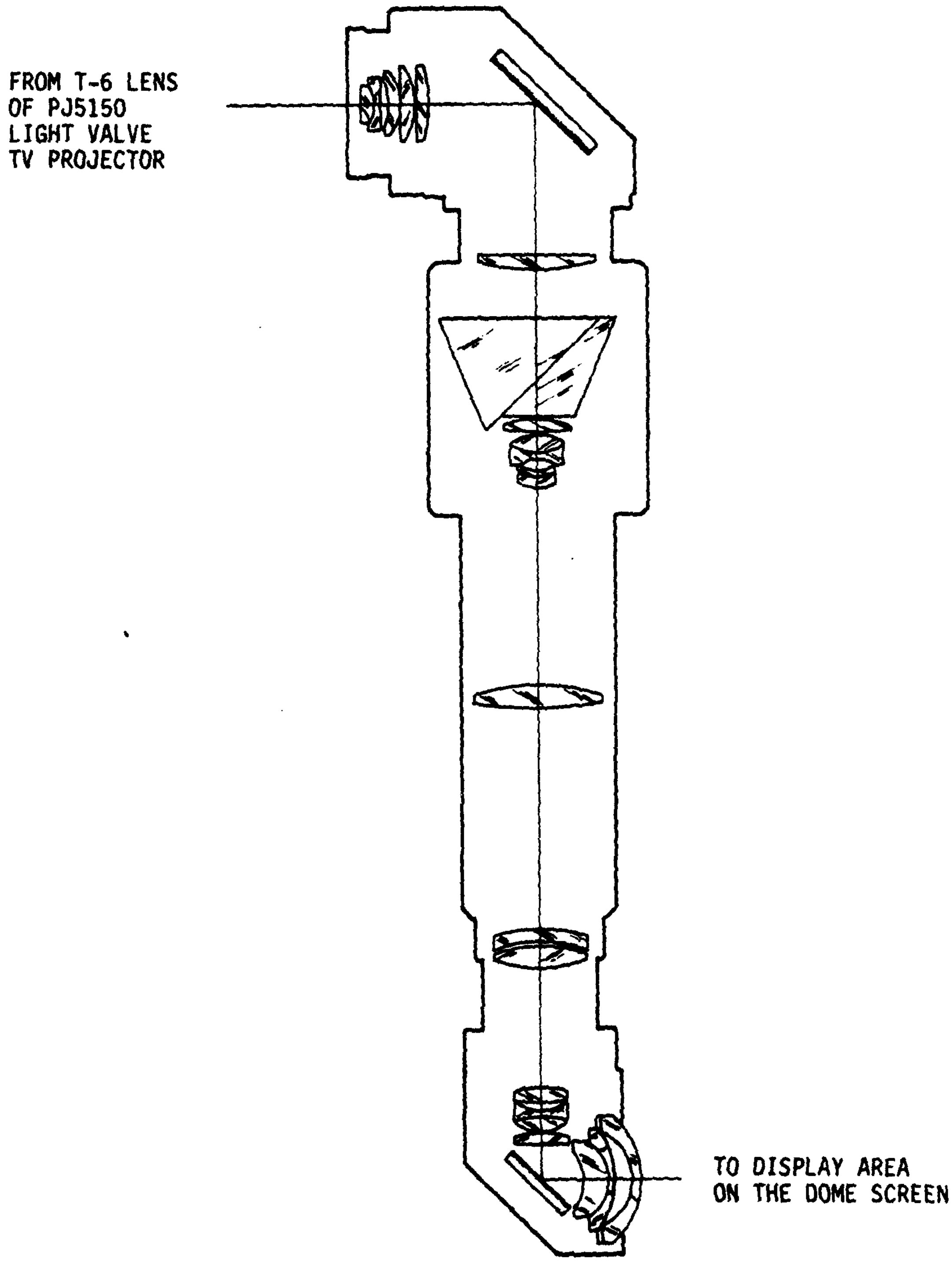

Figure 7. Special Projection Lens.

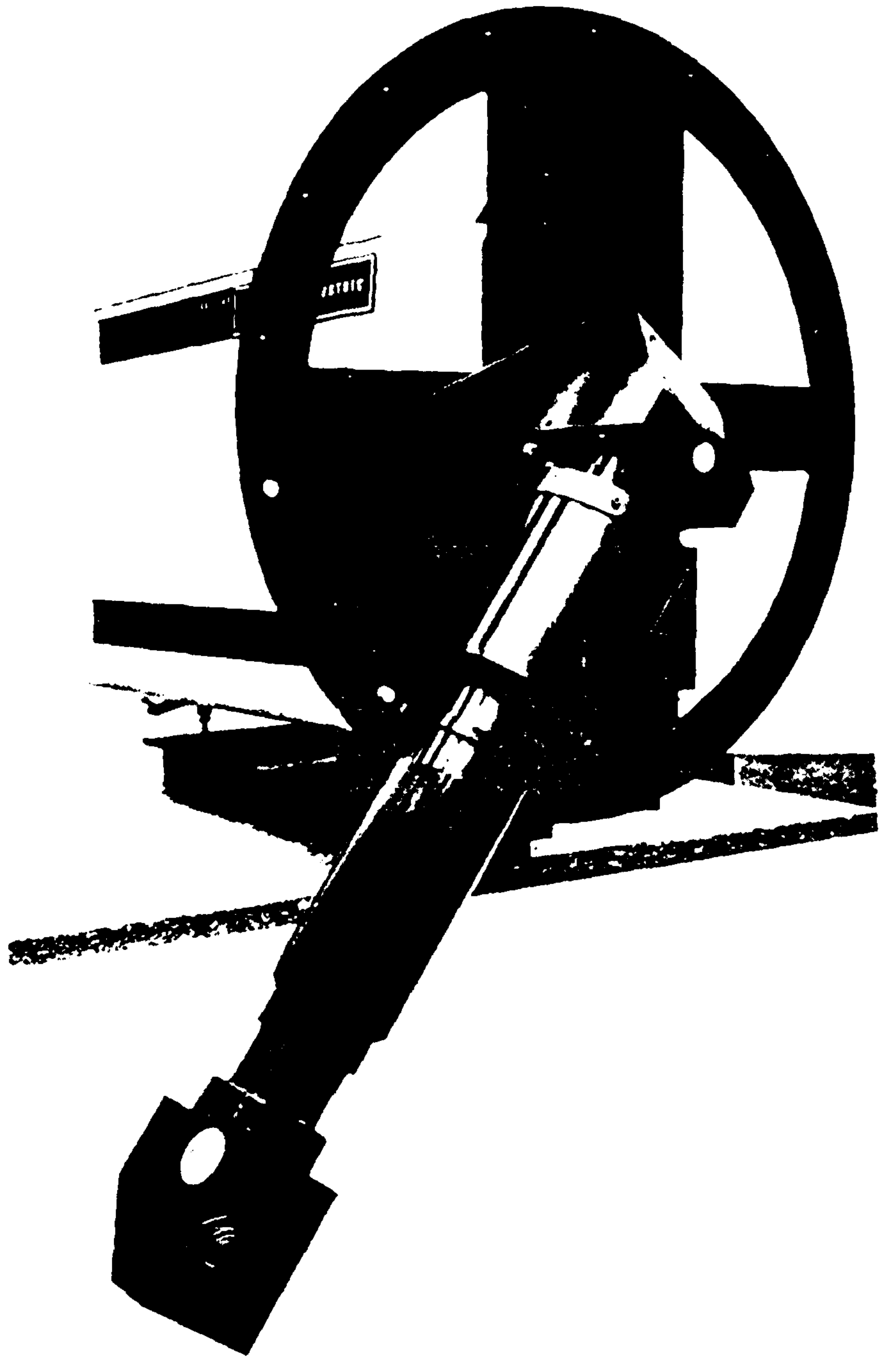

Figure 8. Lens and Projector Configuration.

(2) about the long arm axis of the lens; and is compensated for any image roll by a Pechan prism. Resolution for the two lenses used in the VTOL visual system is 211 cycles per millimeter and 149 cycles per millimeter, respectively; with transmission at 56.7% and 53%, respectively. Characteristics of the visual system are summarized in Table 2.

TABLE 2. SUMMARY OF VTOL VISUAL SYSTEM

Image Source	GE CIG, 2 channels
Projectors	2 GE PJ5150 color light valves
Special Lens	114° FOV, 32" extension, rotatable 360° about two axis
Display FOV	160°H (80° + 80°) x 70°V (+20° up, -50° down)
Display Screen	34 foot diameter spherical dome (display area 280° horizontal x 195° vertical from -55°)
Screen Gain	x1 for matte white x8 for beaded screen (optional)
Luminance	0.5 foot lamberts for matte white 4.0 foot lamberts for beaded screen
Contrast Ratio	12:1
Resolution	10 - 12 arc min/optical line pair
Gaming area	40 nm radius
Update Rate	60 Hz
TV Scan Lines	1023 (2:1 interlace)
Light Valve Output	650 lumens

COMPUTER IMAGE GENERATION

When integrated with the VTRS, the CIG System provides real-time television raster displays of simulated flight environment scenes. The scenes are generated as a function of environment data input to the CIG System's

PDP-11T55 general-purpose computer from disc storage and from dynamics data provided by the VTRS SEL 32/75 computer and flight simulator.

The environment data is embodied in a data base developed previously in a non-real time facility and recorded on mag tape. Each data base is characterized by its models, objects, special features and given gaming area. For real-time CIG the data base is loaded on a mag disc, input to the PDP-11T55, processed with the dynamic flight data from the VTRS computer and flight simulator then input to the image processors. This processing cycle, updated every 1/60 second, through the general-purpose computer is termed Frame I which also identifies the CIG hardware subdivision performing the cycle. Two additional cycles are performed in the image processor. They are identified as Frame II and Frame III. These cycles are also performed every 1/60 second, running concurrently with Frame I.

In Frame I the CIG computer receives data from the VTRS computer consisting of own aircraft position and attitude; moving model position and attitude; environmental control (i.e., cloud parameters, fog, night lighting selection, etc.); and discrete control functions as applicable. The CIG computer generates viewpoint and orientation information for own aircraft and any other moving models within the gaming area. The resulting data are transferred to the Frame II image processor. Frame I also outputs information to the operator's console. Real-time scene computations are performed in Frame II from the data base stored in the Frame II core memory. A true perspective, two-dimensional image is computed for each of the two display channels. Functions performed in Frame II include processing of sun angle, vertices, shading, faces, edges, color, point light ordering and priorities. This information, a block of edge data words, a block of point light data words and a face priority list is transferred to Frame III at the start of each processing cycle.

Frame III converts the image data into video synchronized for standard raster format having two-to-one interlace. The significant functions of Frame III are a point light generator, edge/shading generator, edge orderer, priority resolver and a video processor for each display channel. Frame, field, line and element syncs, as required, are received in Frame III from the master timing function. The video processors provide full-color video in RGB format.

The CIG system also provides for distortion correction. The dome display used for VTOL, without this correction, exhibits geometric distortion as a result of the viewpoint and projection points not coinciding. Straight lines from the projector appear as curved lines from the viewpoint. The optics also give distortion. The combination of the two distortions is not symmetrical and the correction system is necessarily complex. Basic functions performed include mapping of vertices, edges and segmenting edges. The correction system also provides for matching adjacent raster edges in the dome display.

For a complete detailed description of the CIG and distortion correction see NAVTRAEQUIPCEN Technical Report 76-C-0048-1 (Morland and Michler, 1981).

EXPERIMENTER/OPERATOR STATION

The Experimenter/Operator (E/O) station provides the capability to interact with the computer and flight simulator for the purpose of developing, controlling, monitoring and recording the experiment. The station is a three-rack turret console with four computer-driven CRT displays, one video CRT display, a hard copy unit, a keyboard, a joy stick for remote aircraft control, various discrete control and readout switches and communications with the subject and other operator personnel. Some of the more pertinent features of the E/O station are:

Two E/O station CRT displays are dynamically refreshed calligraphic stroke displays for graphic presentation. One displays aircraft instruments and indicators and the other displays mission plots.

The E/O station also has two alphanumeric CRT displays used for planning and status listing from the computer. The contents of these CRTs can be printed out on the hard copy unit for immediate reference.

Initial conditions for the aircraft can be selected as well as environmental conditions.

The beginning and end, as well as ideal (desired) performance, with tolerances, can be specified with parameters selected by the Experimenter/Operator (E/O). During a maneuver selected and out-of-tolerance parameters are identified and recorded. The maneuver may be initiated manually or automatically by having the subject achieve prespecified flight parameters.

On line data processing providing for the generation of up to 20 measures per maneuver is available. Measures consist of selected transformations (such as average absolute value) operating on selected performance parameters and are calculated immediately on line after a maneuver.

Up to 40 parameters may be selected for simultaneous recording at 30 times/sec during a maneuver. These include aircraft parameters, motion parameters, operator input parameters, and subject physiological parameters.

Freeze with continue/reset to initial maneuver, to the initial conditions of another maneuver, or replay of up to five minutes is available.

Printout of storage scope information plots and other selected information (such as aircraft status) is available.

Computer error scores of elevation angle, azimuth, position, and altitude are available for display and printout during a maneuver.

An off line data processing mode is available, where recorded data are selected for transformation to provide performance measures, and where statistical analyses are performed.

SECTION IV

SUMMARY

The VTOL Simulator, a research tool, provides the means to investigate visual system issues that are unique to vertical take off and landing aircraft. Essential to this mode of flight is the large downward field-of-view available to the pilot. The LAMPS MK III Seahawk (SH60B) helicopter was chosen as the basic simulator configuration because it is currently undergoing development and represents the Navy's most advanced VTOL type aircraft. Demonstration and evaluation of visual system technology and pilot performance supports current acquisitions as well as planned acquisitions for future systems.

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